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36 separate items are enclosed

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✓ Spreadsheet
✓ DTS

MEMORANDUM FOR PRS (~~Contractor~~/In-House Publication)

FROM: PROI (TI) (STINFO) 15 June 1999

SUBJECT: Authorization for Release of Technical Information, Control Number: AFRL-PR-ED-TP-FY99-0144
Tim Miller , "Mixed-Mode Fracture in a Rubbery Particulate Matrix"
6th Annual International Conference on Composites **(Public Release)**
Vu/Graphs

Mixed-Mode Fracture in a Rubbery Particulate Composite

Timothy C. Miller
Air Force Research Laboratory

Sixth Annual International Conference on Composites Engineering
Orlando, Florida
June/July 1999

Outline of Presentation

- Introduction
  - What is the problem?
  - How do we solve the problem?
- Experimental Procedure
  - Procedure Followed
  - Difficulties Encountered
- Results
  - Crack Initiation Toughness Results
  - Kink Angle Results
  - Crack Growth Results
- Conclusions and Recommendations for Future Work

Problem Statement

Reasons for Examining Mixed-Mode Cracking

- Damage During Manufacture or Handling May Cause Cracks That Are Later Subjected to Mixed-Mode Loading
- Cracks Near or at Interfaces Are Inherently Mixed-Mode Cracks
- Analysis of Mixed-Mode Cracking is Substantially More Complicated Than for Mode I Cracks

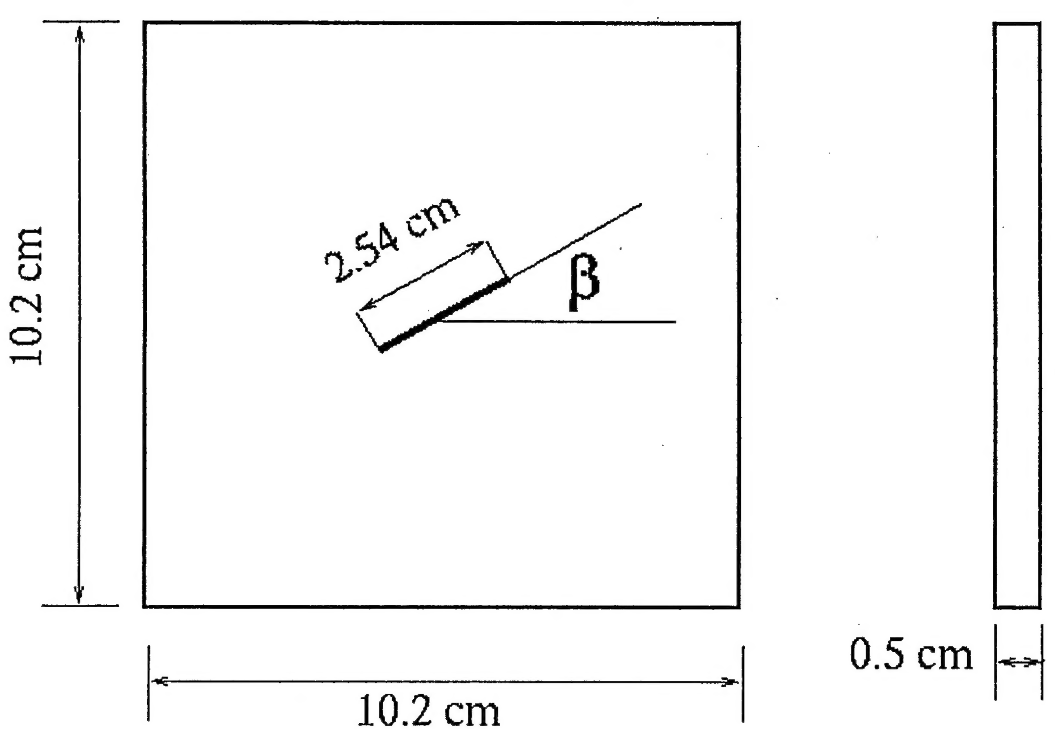
Method of Solution

- Test Various Mixed-Mode Specimens
  - Measure Load at Initiation
  - Measure Crack Length (Simplified Manner) Versus Time
  - Measure Kink Angle
- Use Finite Elements and Experimental Load Measurements to Determine Fracture Parameters at Initiation of Growth
- Use Crack Length Versus Time to Determine Simplified Crack Growth Model
- Use Kink Angle Measurements to Determine if Available Theories Can Adequately Predict Growth Direction

.5

Specimen Geometry for Mixed-Mode Testing

Crack Angles Used Are 0 (Mode I), 15, 30, 45, and 60 Degrees



$$K_I = \sigma\sqrt{\pi a}\cos^2\beta$$

$$K_{II} = \sigma\sqrt{\pi a}\sin\beta\cos\beta$$

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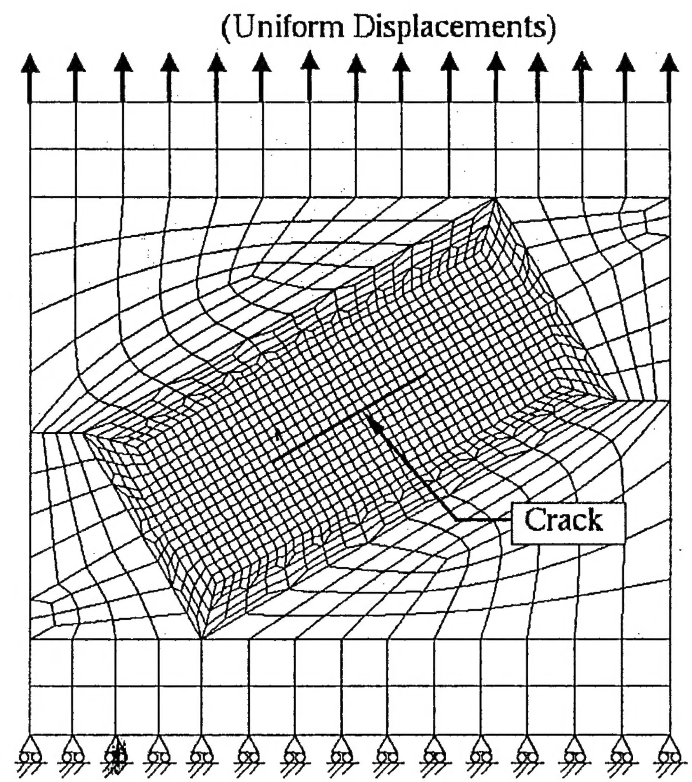
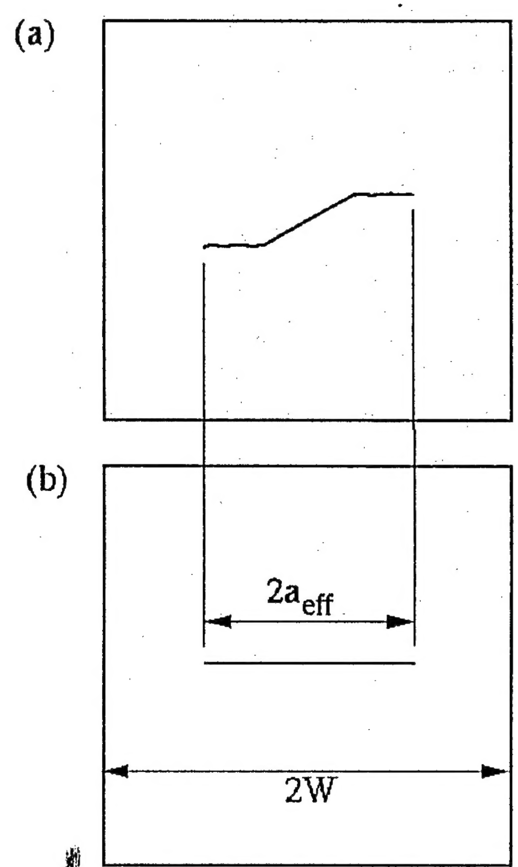
Sample Finite Element Mesh for Computational Models

Displacement Boundary Conditions Are Used, Crack Orientation Shown Here is 30 Degrees



Modeling Mixed-Mode Crack Growth Using a Simplified Approach

Simplified Geometry Can Be Used to Analyze Crack Growth Rates Successfully

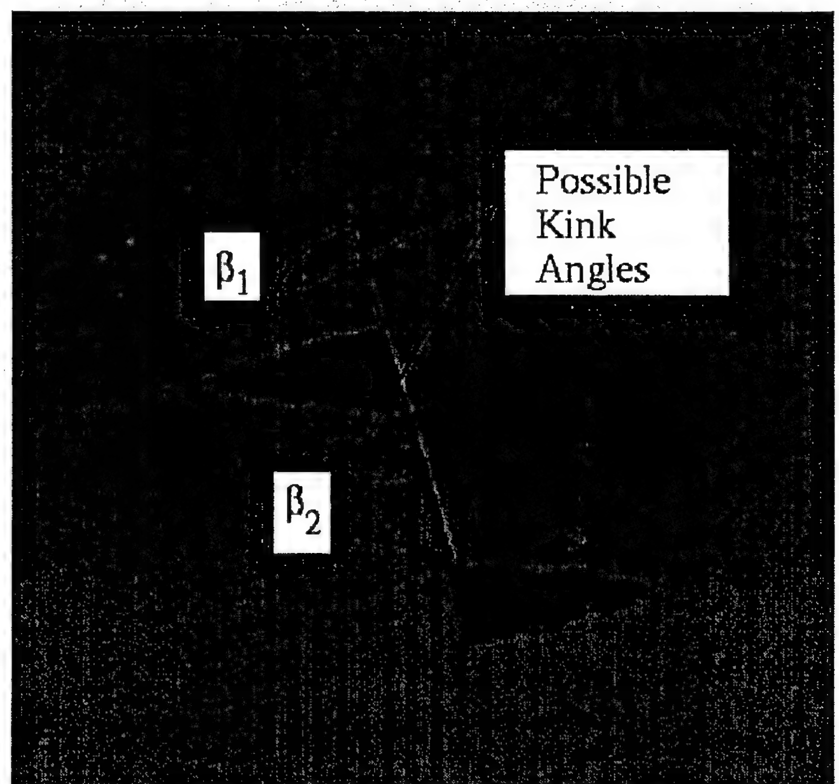


Difficulties Encountered

- Large Deformations Make In-Situ Determination of Kink Angles Difficult
- Mixed-Mode Inititation Toughness Locus is Linked to Micromechanisms That Are Poorly Understood
- Linear Elasticity May Not Be Valid

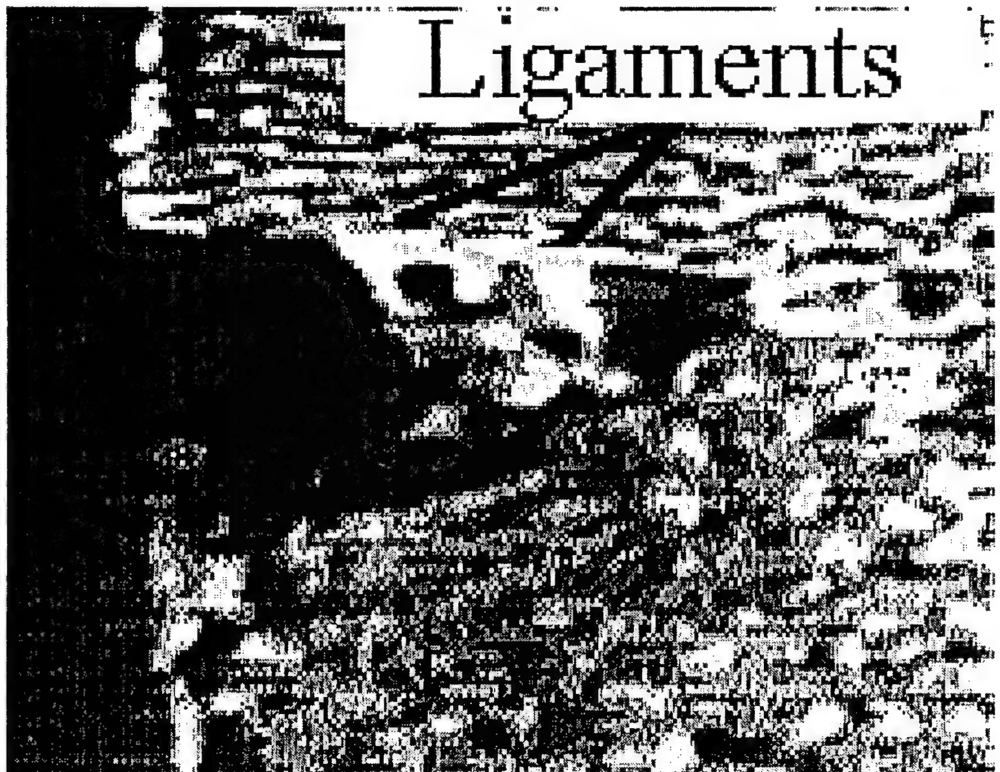
Crack in a Propellant Specimen Shortly After Initiation of Crack Growth

Large Deformations Make Kink Angle Determination Ambiguous



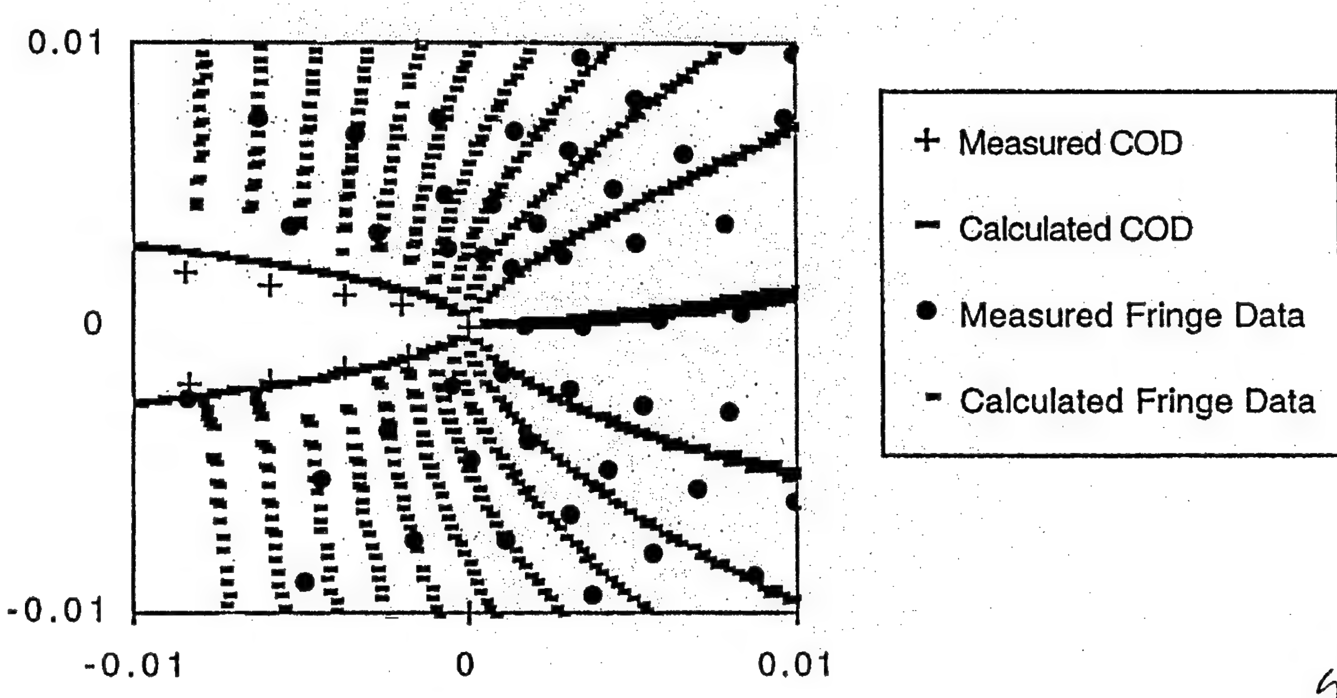
Ligament Bridging Near the Crack Tip in a Rubbery Composite Specimen

Mechanisms Such as Ligament Bridging May Account for Shape of Mixed-Mode Failure Locus in a Rubbery Particulate Composite



Experimental and Computed Moiré Fringes and Crack Opening Displacements for a Rubbery Particulate Composite

Good Agreement Shows That Linear Elastic Fracture Mechanics Works Well



SLIDE WILL BE REWORKED FOR MEETING TO SHOW RELATIONSHIPS MORE CLEARLY.
PGK
14 Dec 90

Results

- Results for Initiation Toughness Show That Elliptical Curve Fit Works Well
- Results for Kink Angle Determinations Show More Deviation From Theory Than Expected
- Use of Simplified Approach to Predict Crack Growth Rate Works Well

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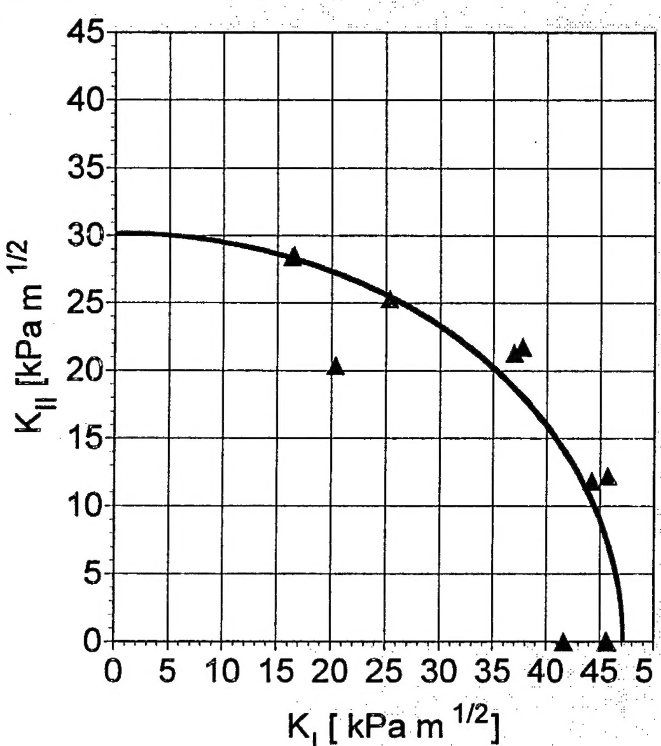
Elliptical Failure Locus for Initiation of Crack Growth

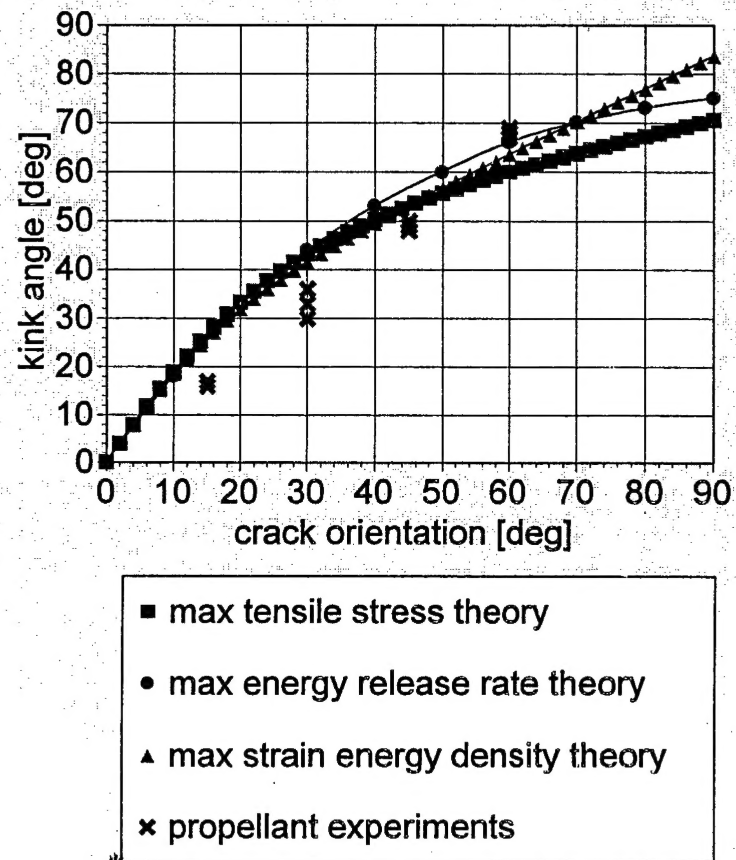
Unlike the Failure Locus for Metals, the Mode I Fracture Toughness is Higher Than its Mode II Counterpart



$$\left[\frac{K_I}{K_{IC}}\right]^2 + \left[\frac{K_{II}}{K_{IIC}}\right]^2 = 1$$

Kink Angles Plotted as a Function of Crack Orientation Angle

Experimental Results Show Some Deviation From Existing Theories



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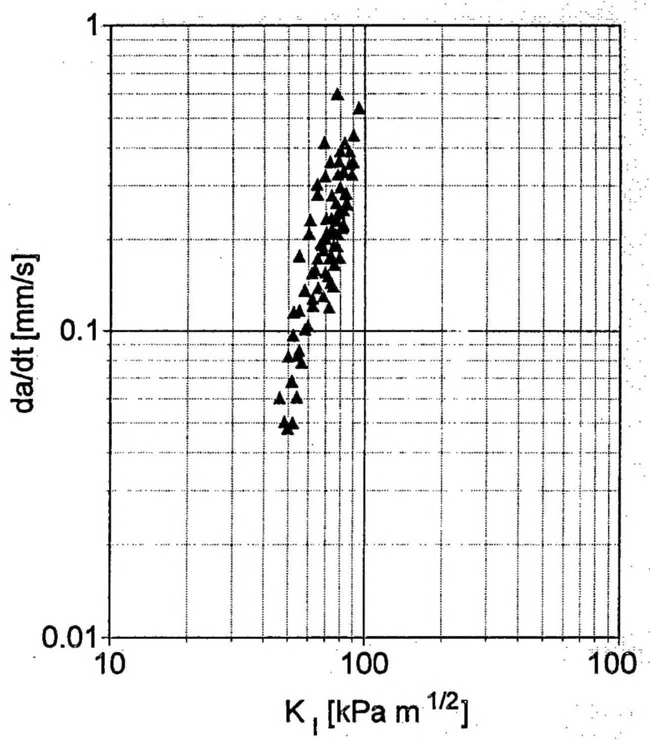
Effective Crack Growth Rate for the Mixed-Mode Experiments as a Function of Stress Intensity

Use of Simplified Approach Shows Agreement Even With Different Levels of Mode Mixity



$$\frac{da_{eff}}{dt} = CK_I^m$$

Conclusions

- Although rubbery particulate composites have viscoelastic properties, high elongations, and complicated failure mechanisms, they can be studied, for a given nominal strain rate, using linear elastic fracture mechanics.
- The complex stress intensity factor failure locus is elliptical.
- The kink angles match available theories best at higher levels of mixity. The best theory appears to be Strain Energy Density Theory, but all of the theories made similar predictions.
- A simpified approach that uses an equivalent mode I crack can be used to predict the crack growth rate for mixed-mode cracks